Experimental summary of SUSY Dark Matter searches at the LHC

Dark Matter @ LHC 2014
25-27/09/2014, Merton College, Oxford

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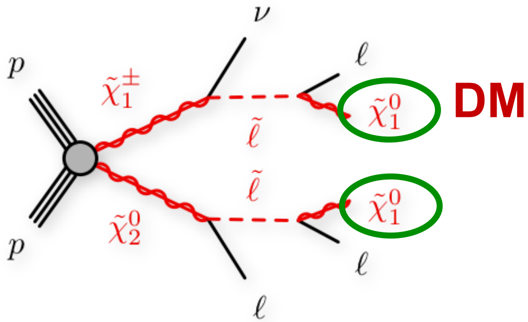
for ATLAS and CMS collaborations

Introduction

- In R-parity conserved SUSY models, the lightest supersymmetric particle (LSP) is a suitable candidate for Dark Matter.
  - Sparticles are produced in a pair, each decays to LSP, leading **large E_T^{miss}**.
  - Mixing of wino, bino and two neutral higgsinos gives four neutralinos.
  - In most models, the LSP is the lightest neutralino or gravitino.

- Search for LSP at the LHC
  - Direct LSP pair production is not accessible due to low cross-sections.
  - **The LSP is typically produced at the end of cascade decays of heavier sparticles.**

    Constrains on the LSP mass depends on the considered mass spectrum.

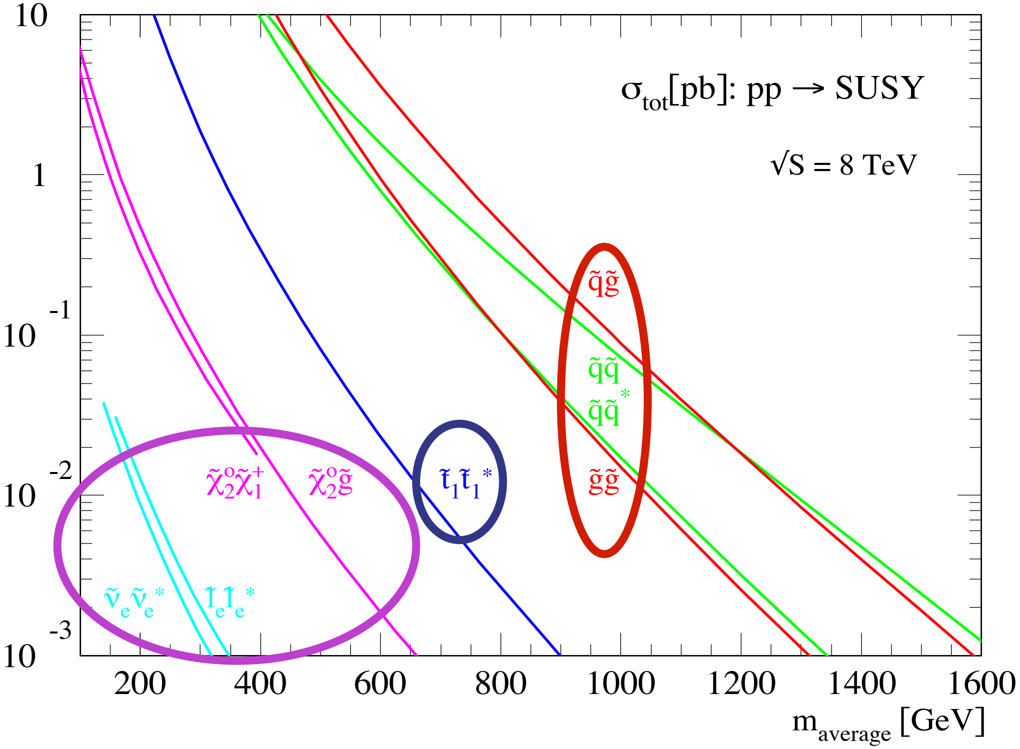


Outline

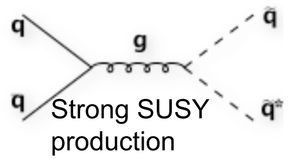
- SUSY search strategy
- Selected SUSY DM results by ATLAS and CMS with the full 8 TeV dataset
  - Inclusive searches for squarks and gluinos
  - Third generation squarks
  - Electroweak production
- Conclusions

SUSY search strategy

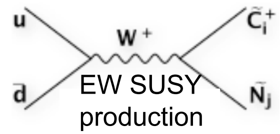
- SUSY pair productions at the LHC:



  - **gluinos and 1st and 2nd gen. squarks** with high cross-section, reachable up to > 1 TeV mass
  - **3rd gen. squarks with moderate cross-section**, up to ~0.5 TeV

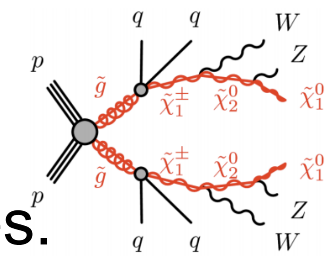


  - **charginos, neutralinos and sleptons** with small cross-section, becoming feasible with the current dataset.



- Sparticles decay into characteristic signatures: e.g. E_T^{miss}, (*b*/*c*-) jets, leptons, and photons.

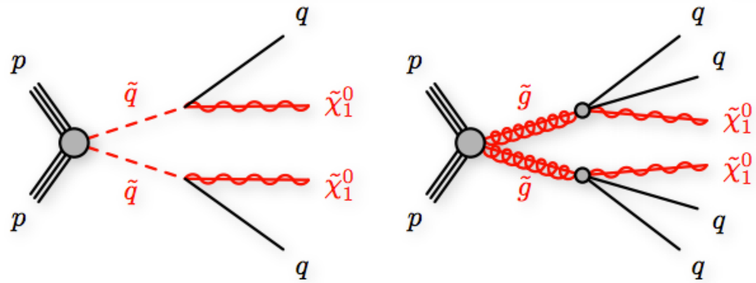
→ Designed various analyses to cover many signatures.

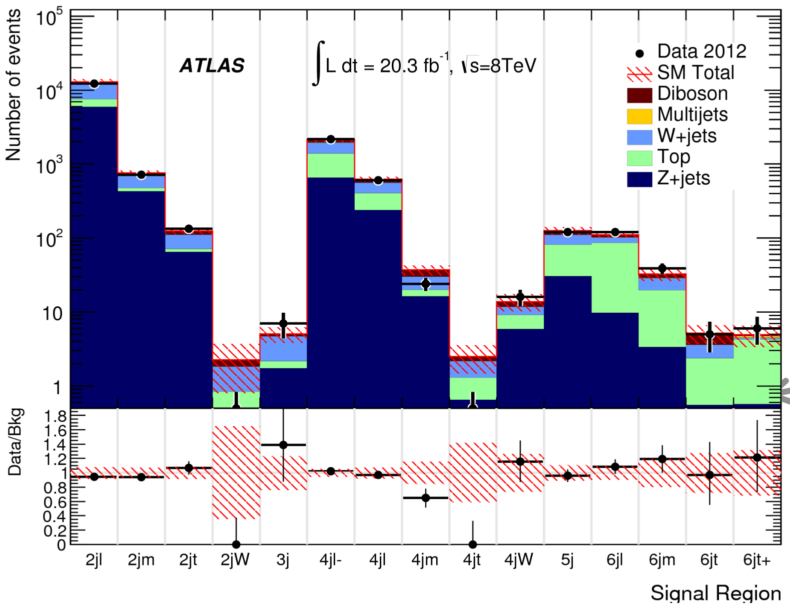


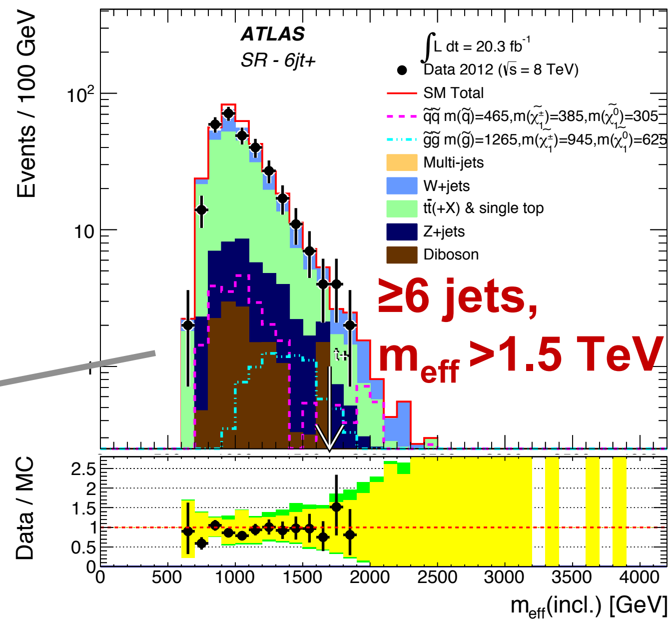
Squark and gluino search in all-hadronic events

arXiv:1405.7875

- Signature: 2 to ≥6 jets + E_T^{miss}
- Wide coverage of inclusive phase spaces by multiple signal regions.
- Discriminating variable: effective mass $m_{eff} = E_T^{miss}$ + scalar sum of jet p_T





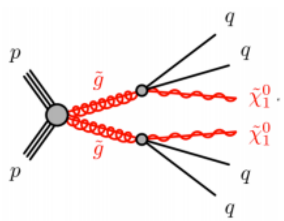


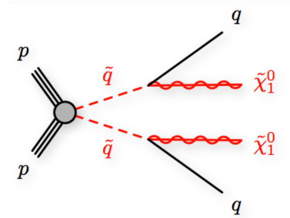
- Agreement between data and SM background prediction.

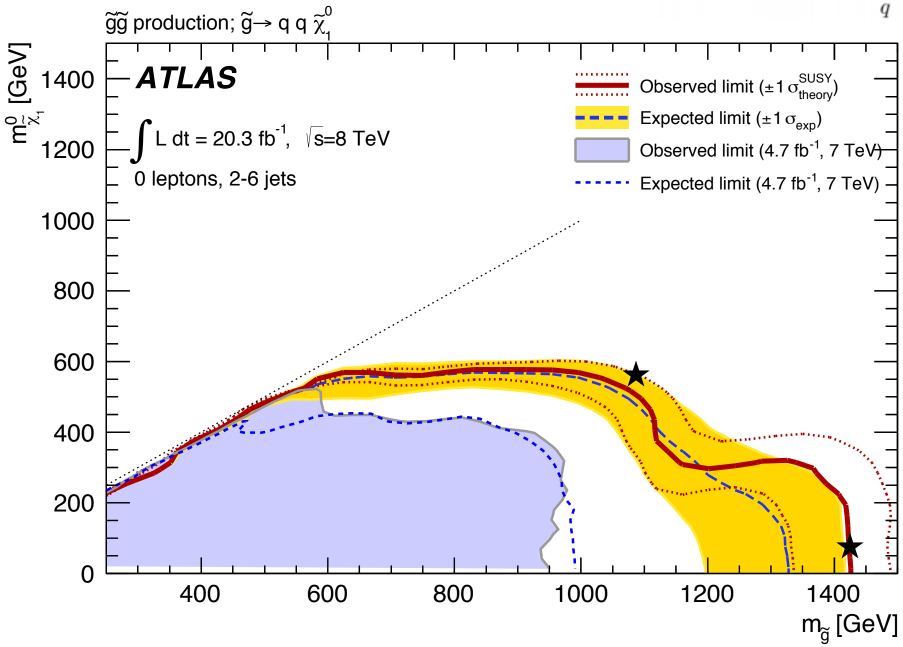
Interpretation

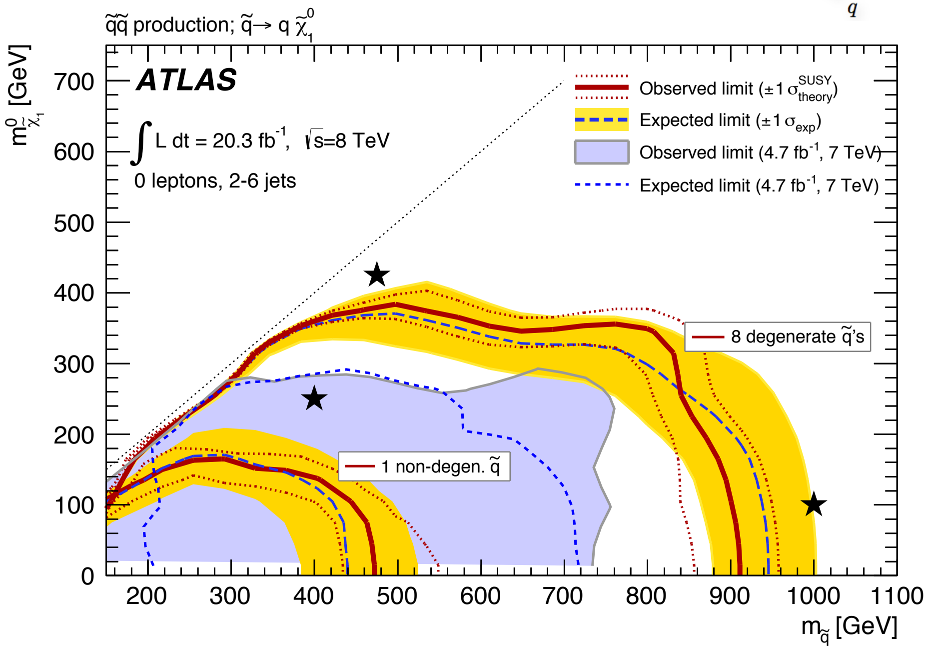
arXiv:1405.7875

- Results are interpreted in terms of squark and gluino pair production.









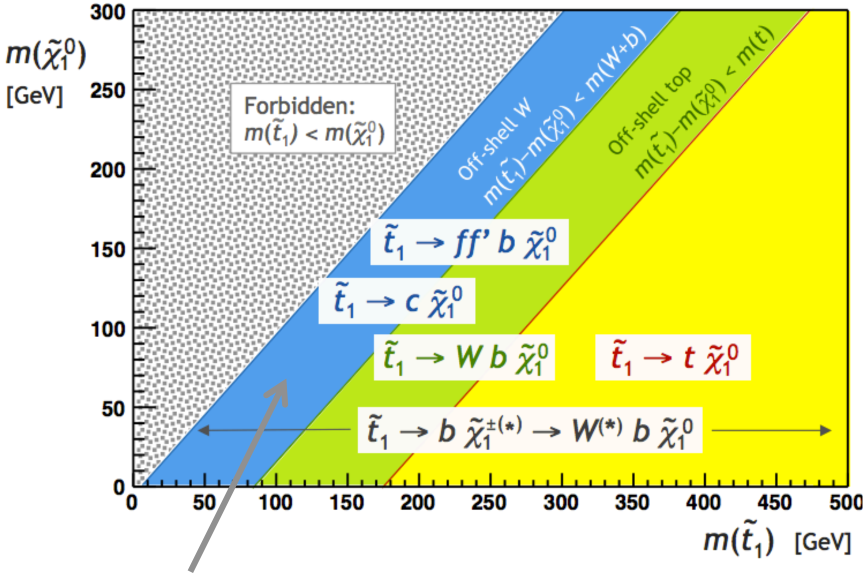
95% CL exclusion at massless LSP:

m_{gluino}<1330 GeV

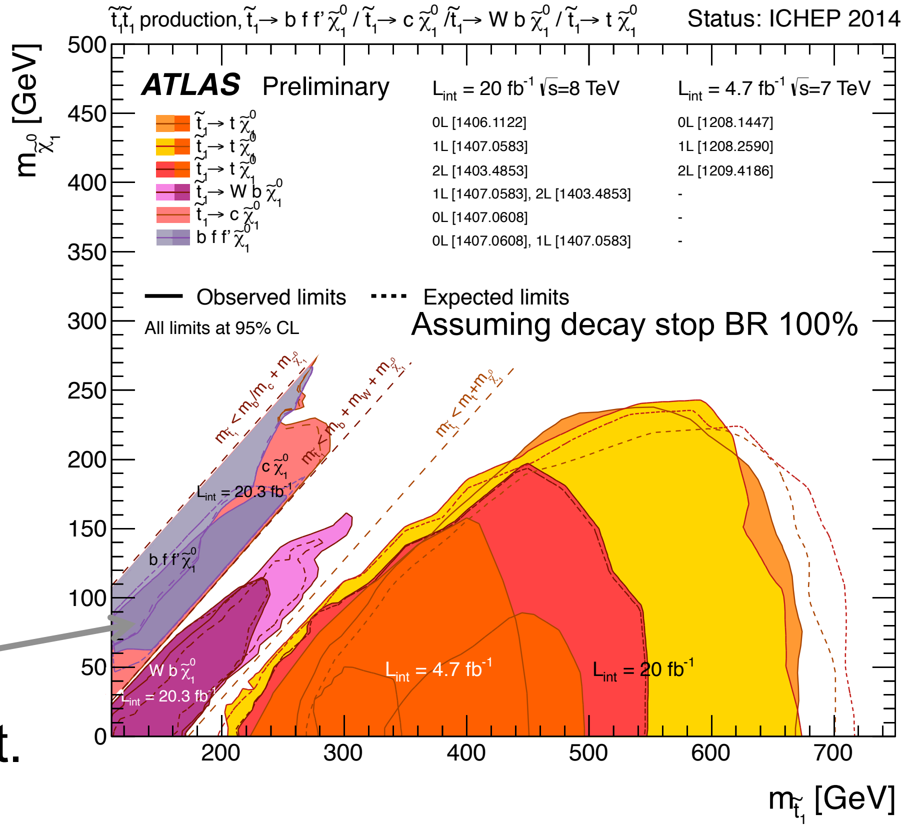
m_{squark}<850 GeV

Searches for stop pair production

- Large spectrum of possible stop decays is covered by several dedicated analyses with 0/1/2-leptons+(*b*/*c*-)jets.



Even compressed region is fully covered by dedicated analyses with *c*-jet and ISR-jet.



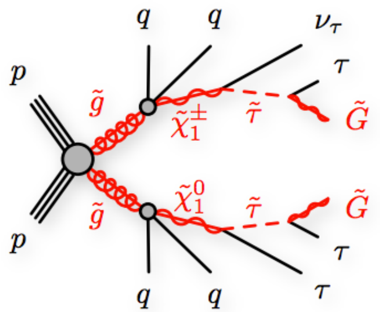
In $\tilde{t}_1 \to t \tilde{\chi}_1^0$, exclusion at massless LSP: m_{stop}<645 GeV. Up to m_{LSP}<230 GeV.

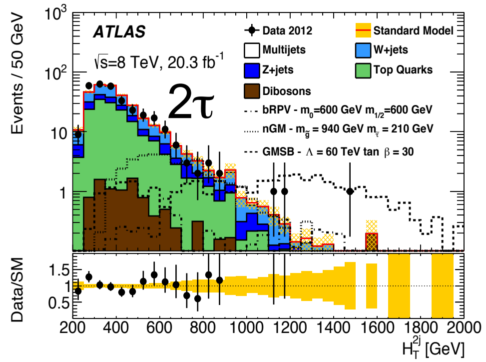
GMSB models: gravitino LSP

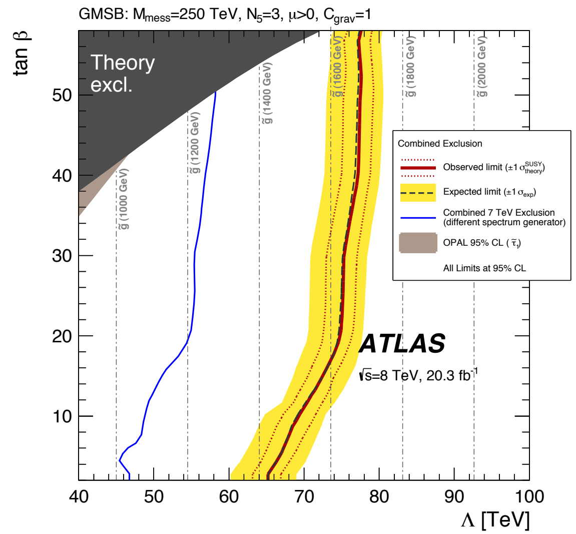
arXiv:1407.0603

- Signatures depend on the next-to-lightest sparticles (NLSP).

- Stau NLSP
- Signature: τ + jets + E_T^{miss}





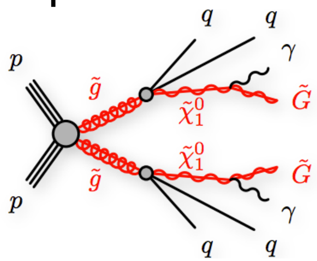


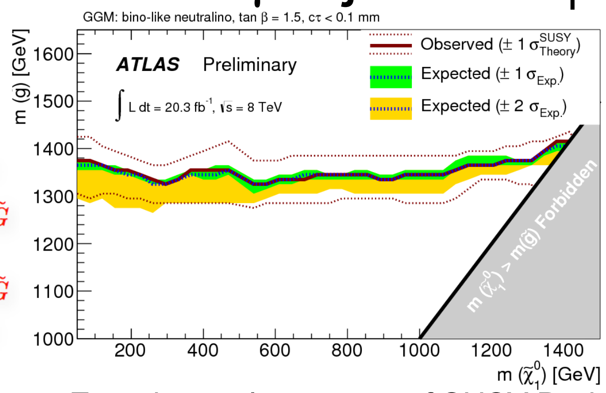
- Bino NLSP

ATLAS-CONF-2014-001

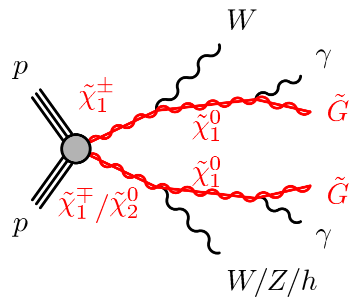
- Signature: 2 γ + jets + E_T^{miss}

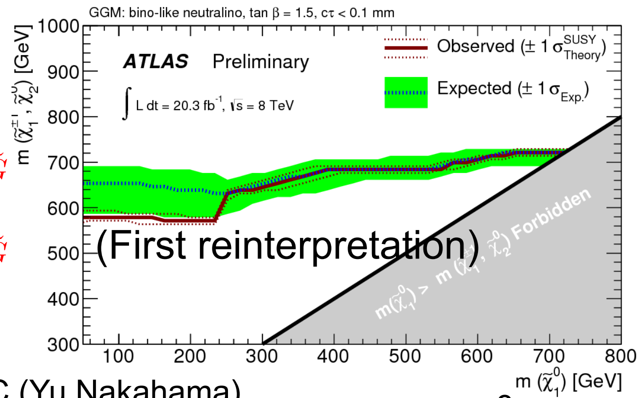
Gluino production





EW production

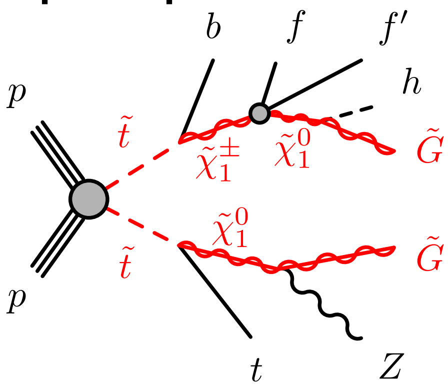




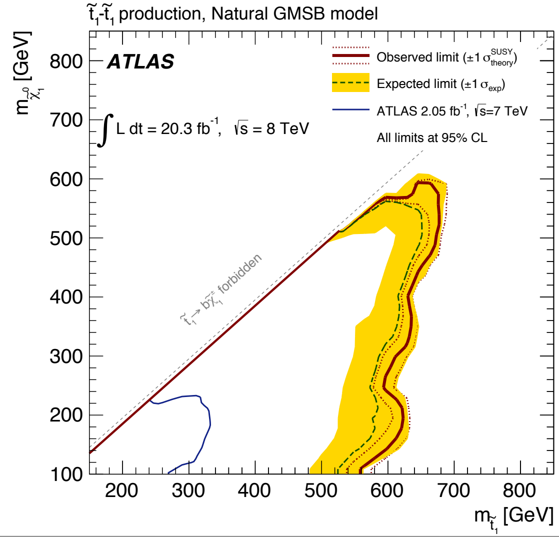
GMSB models: Higgsino NLSP

Eur. Phys. J. C (2014) 74:2883

- Higgsino NLSP in stop pair production
- Signature: Z + *b*-jets

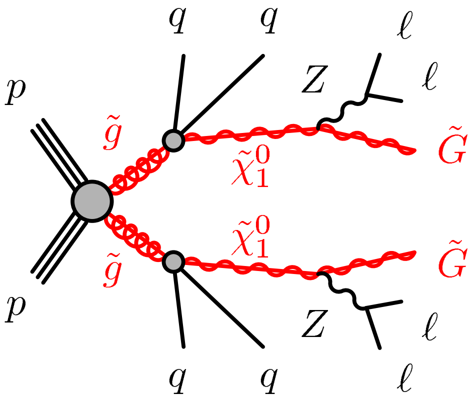


Stop production

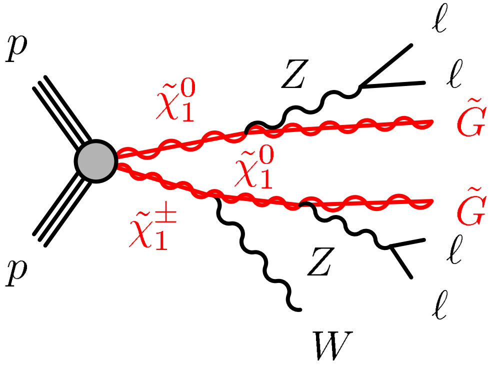


- Higgsino NLSP in gluino and EW productions
- Signature: ≥ 4 leptons via Z

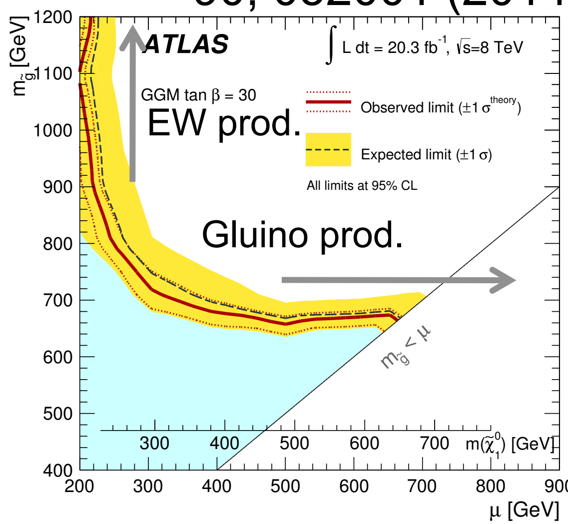
Phys. Rev. D. 90, 052001 (2014)



Gluino production

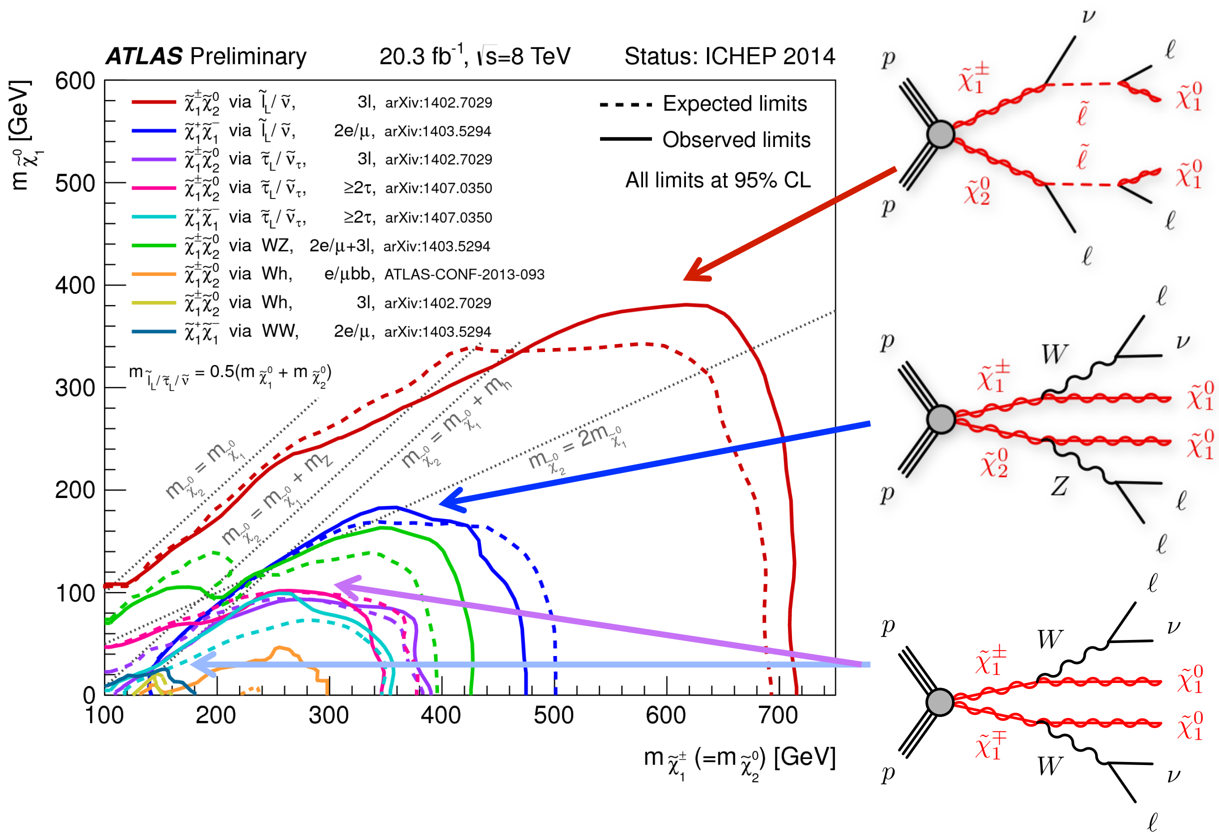


EW production



Searches for chargino/neutralino production

- Clean signature: multi leptons, depending on slepton masses and gauge mixture.
- Many possible models are covered by several comprehensive analyses.



Large cross-section.
3 lepton final states if light sleptons:
exclusion up to m_{LSP}<~380 GeV.

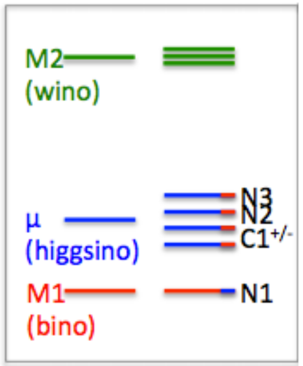
If heavy slepton, smaller cross-section to lepton WZ/h with 3/2 leptons:
up to m_{LSP}<~180 GeV

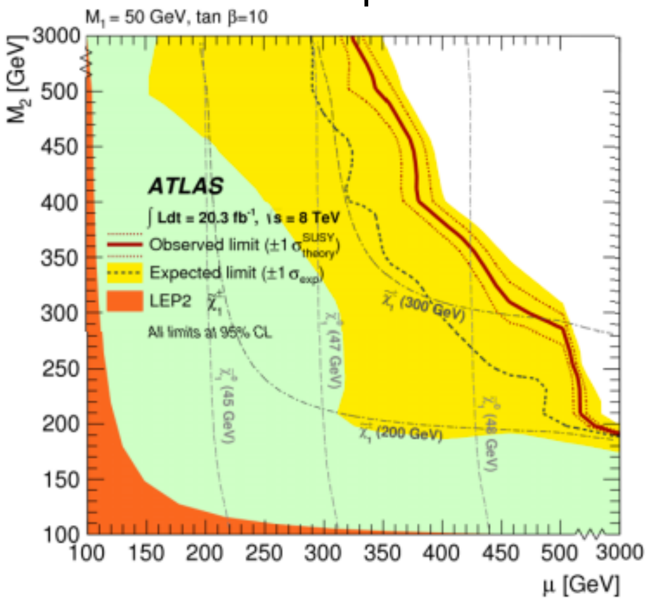
Tiny cross-section of chargino pair production via WW with 2 leptons.
Sensitivity increased if light stau.

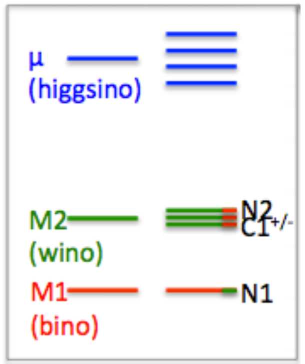
Interpretation of EW production in pMSSM

JHEP 05 (2014) 071

- Phenomenological MSSM (pMSSM) can put generic constraints on most of the phenomenological features of the RPC MSSM.
- Interpretation of 2-lepton+3-lepton analyses in pMSSM:
  – on higgsino μ- wino M_2 mass-plane also with very large slepton masses.
  – Assumption is bino mass M_1 = 50GeV and tanβ = 10.



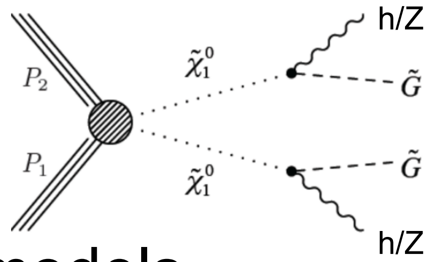




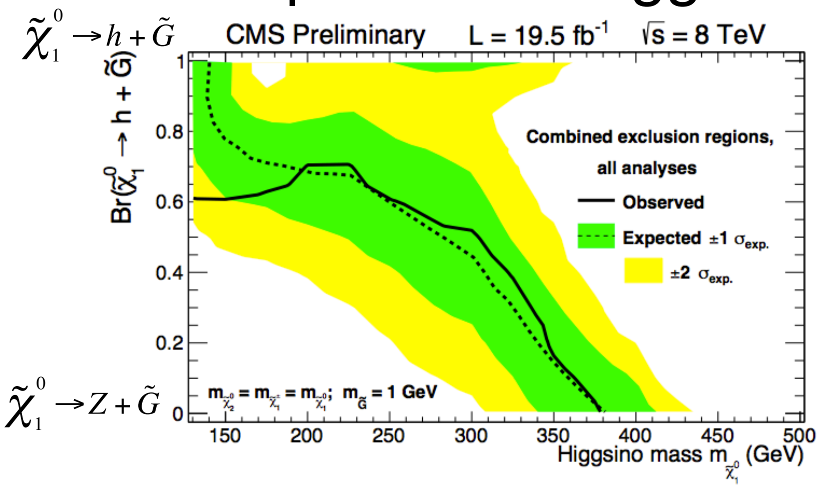
Search for EW production with Higgs

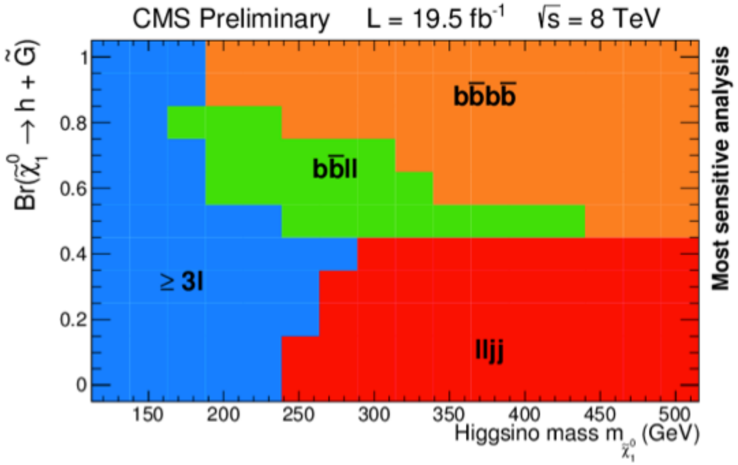
CMS-SUS-14-002, arXiv:1409.3168

- Higgs discovery opens up new SUSY searches:
  - Lightest neutral *CP*-even Higgs (h) expected to be SM-like, if others heavy.
  - Neutralino can decay to h/Z+LSP.
- CMS performed comprehensive search program with di-boson + E_T^{miss} including hh, Zh, Wh.
  - h→ZZ, WW, γγ, *bb*



- Interpretation: Higgsino NLSP in GMSB models

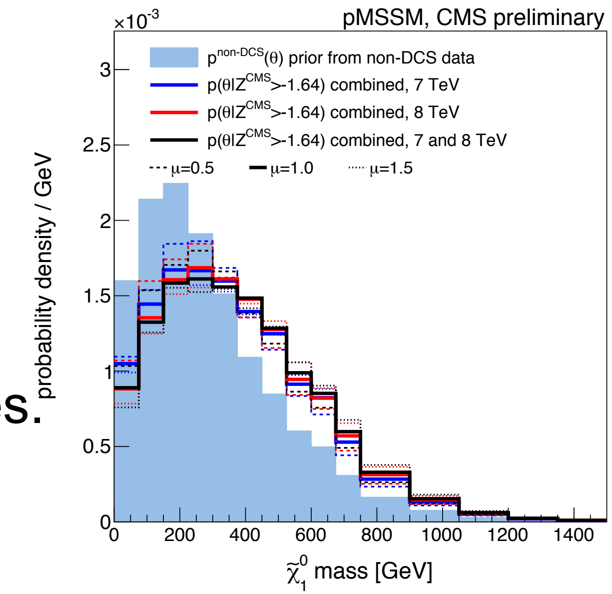




pMSSM interpretation of CMS results

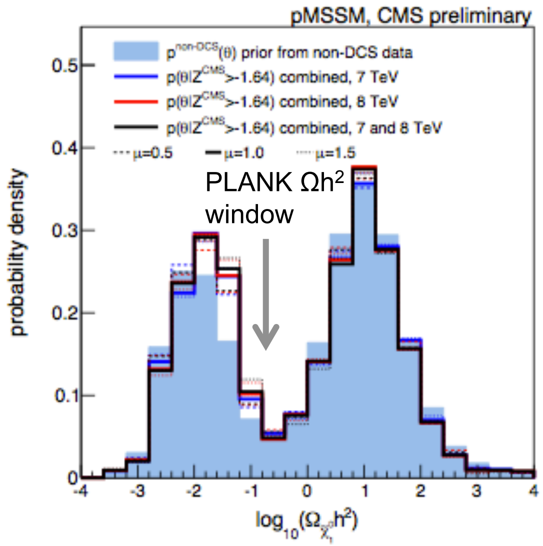
CMS-SUSY-13-020

- CMS reinterpreted 7 and 8 TeV searches in pMSSM.
- pMSSM points were selected to be compatible with LEP exclusions and flavor physics results, assuming neutralino LSP and sparticle masses < 3 TeV.
- Constrained by the CMS EW and inclusive H_T+E_T^{miss} (+*b*-jets) searches.
  - Blue filled areas show the prior distributions before taking into account CMS analyses. Black lines show posterior distributions after including the CMS analyses.
  - Data slightly disfavor small neutralino masses.

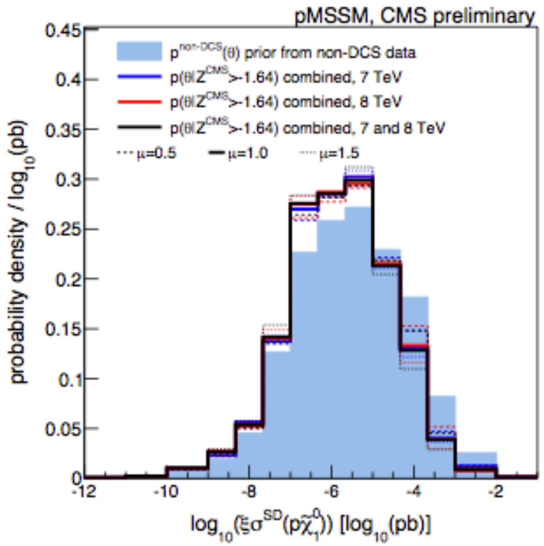


Constraints on DM-related quantities

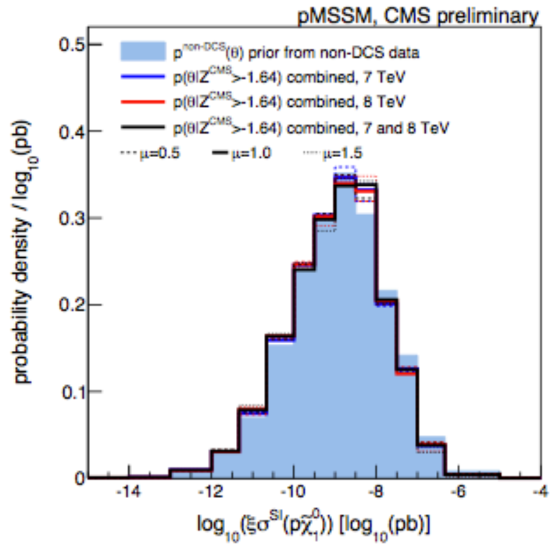
CMS-SUSY-13-020



Neutralino relic density



Spin-dependent direct DM detection cross-section



Spin-independent direct DM cross-section

- If a series of SUSY signals is observed, features of cascade decays will help to determine DM-related quantities.
- Demonstrated the influences of the CMS SUSY searches on DM-related quantities:
  - CMS data slightly prefer lower densities.
  - lower p- $\tilde{\chi}_1^0$ scattering cross sections are marginally favored.

Conclusion

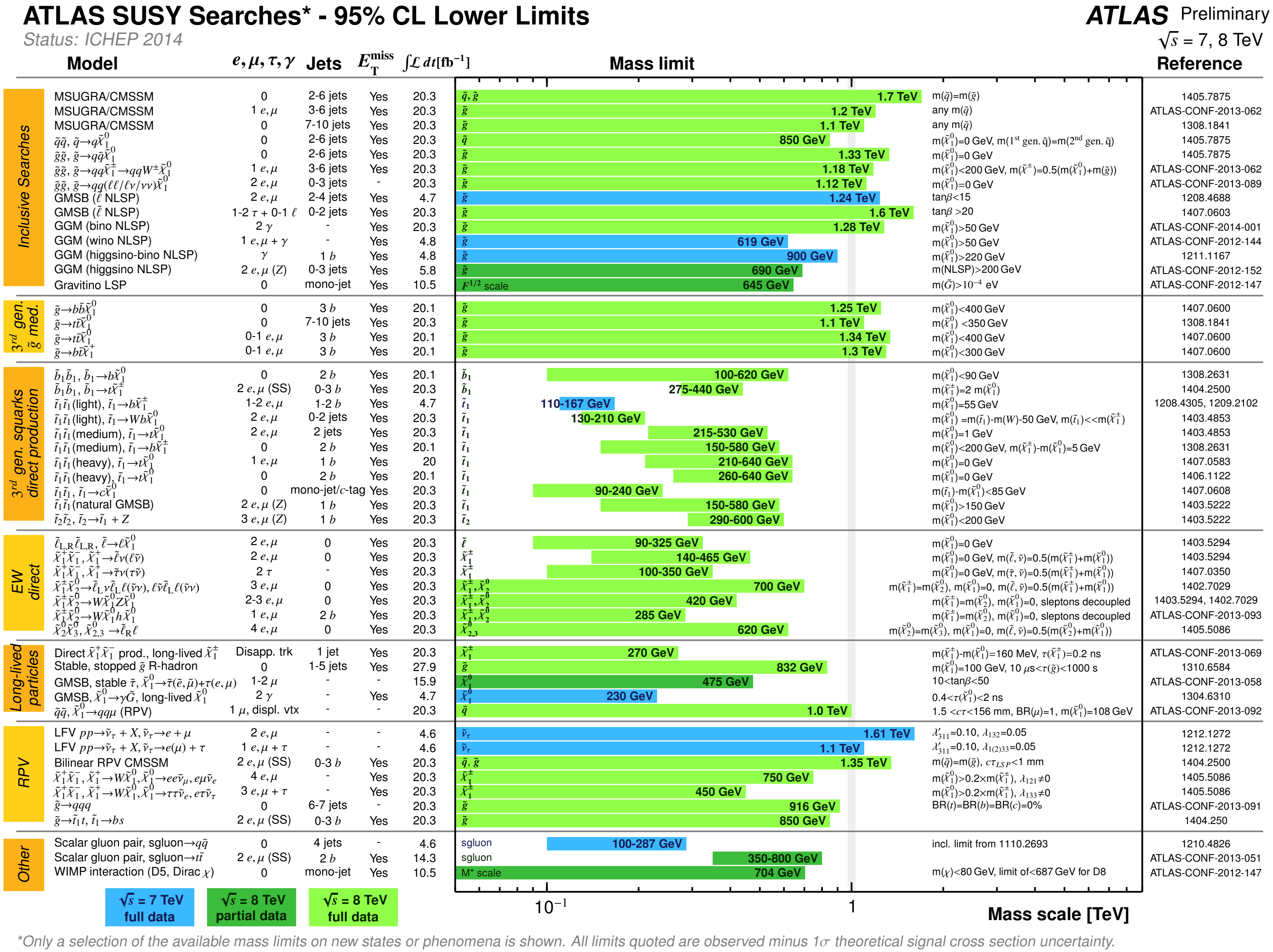
- ATLAS and CMS performed comprehensive programs of SUSY DM searches with the 8 TeV full dataset to cover as many signatures and models as possible.
  - e.g. Increased coverage for difficult SUSY regions. Performed new analyses with Higgs in the SUSY cascade decays.
  - Plenty of public results are available:
    ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
    CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- Run2 data at 13 TeV will explore wider phase spaces and further increase discovery potential of SUSY DM.

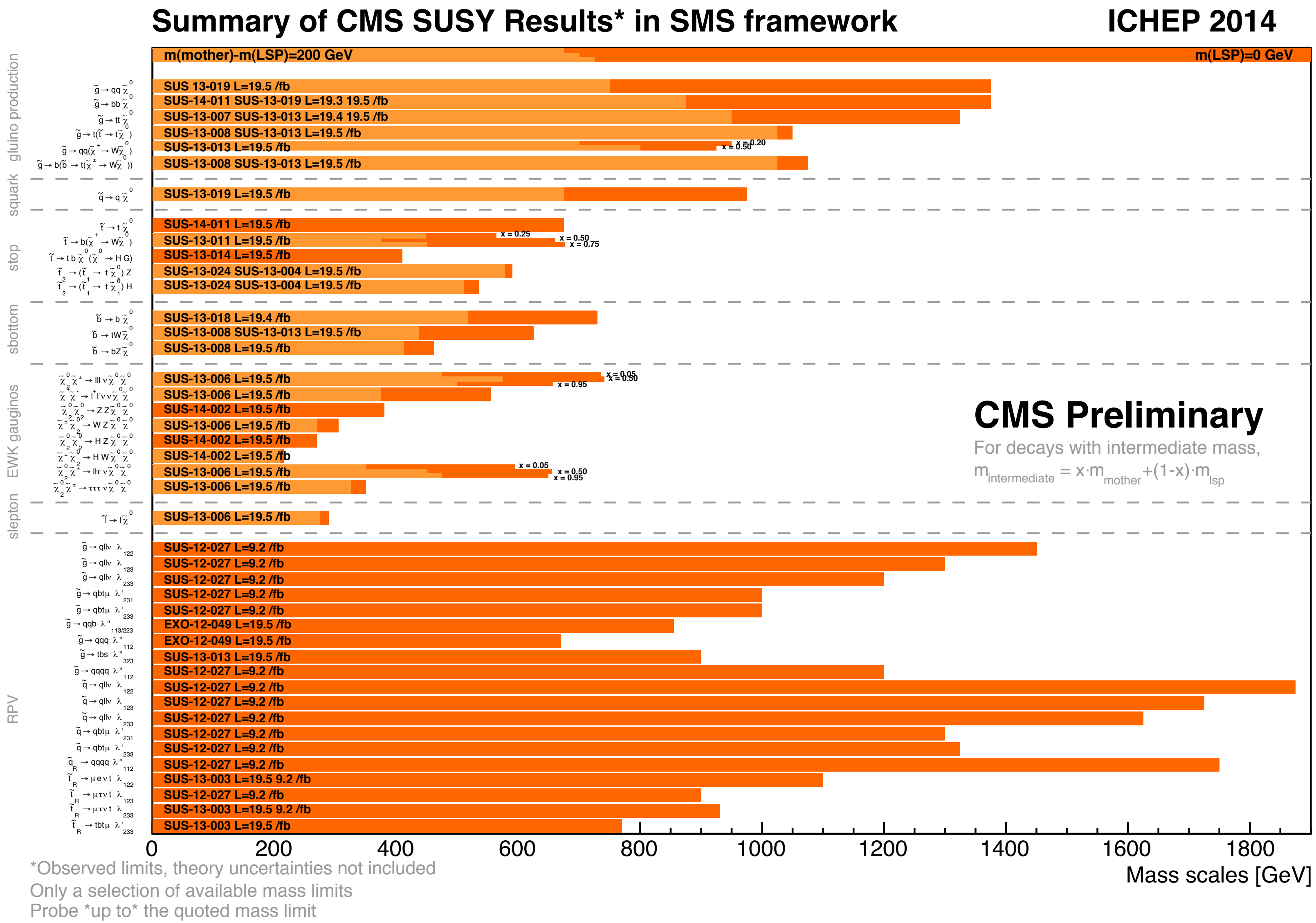
- Searches for DM in SUSY cascade decays are complementary to direct searches.

Backup slides

Summary of ATLAS SUSY results



Summary of CMS SUSY results

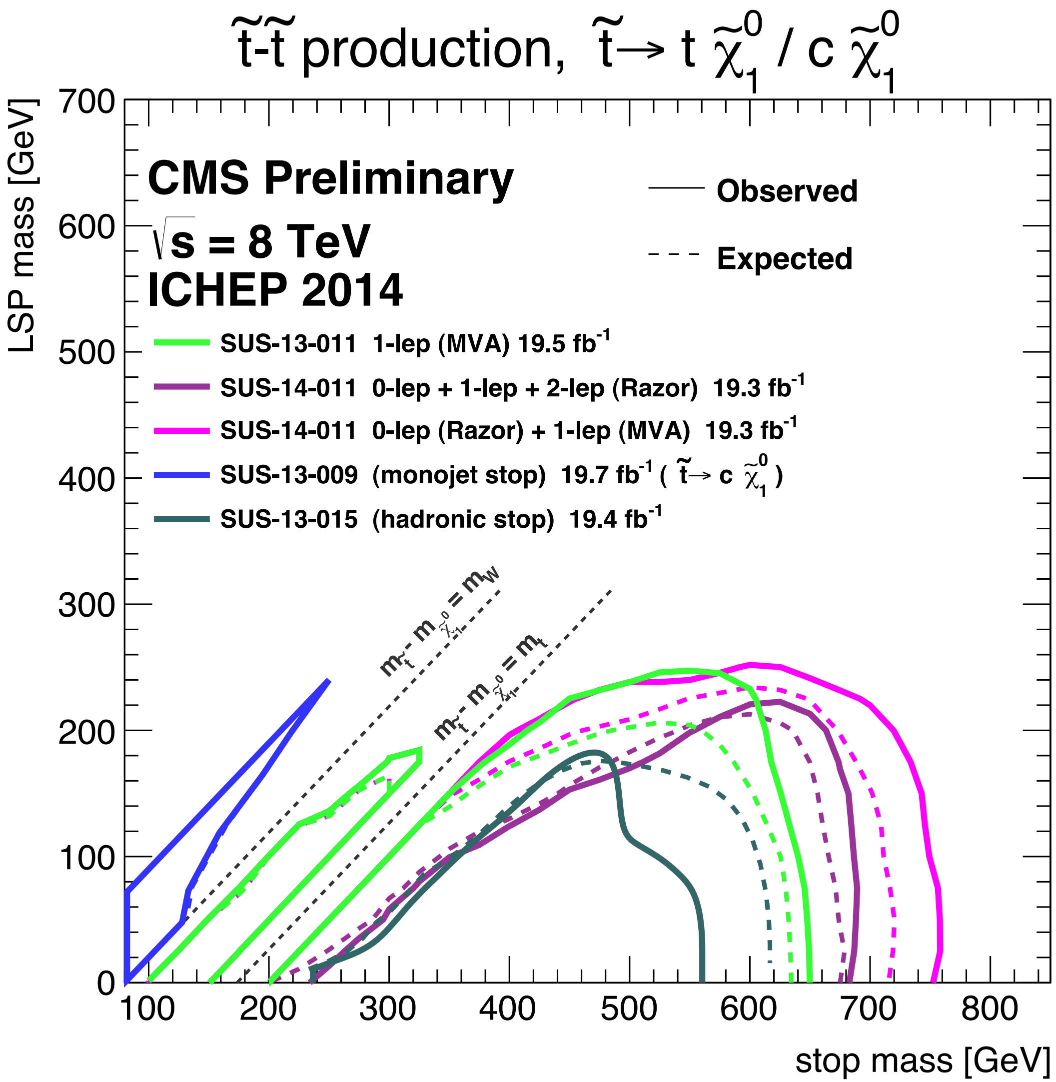


SUSY analysis strategy

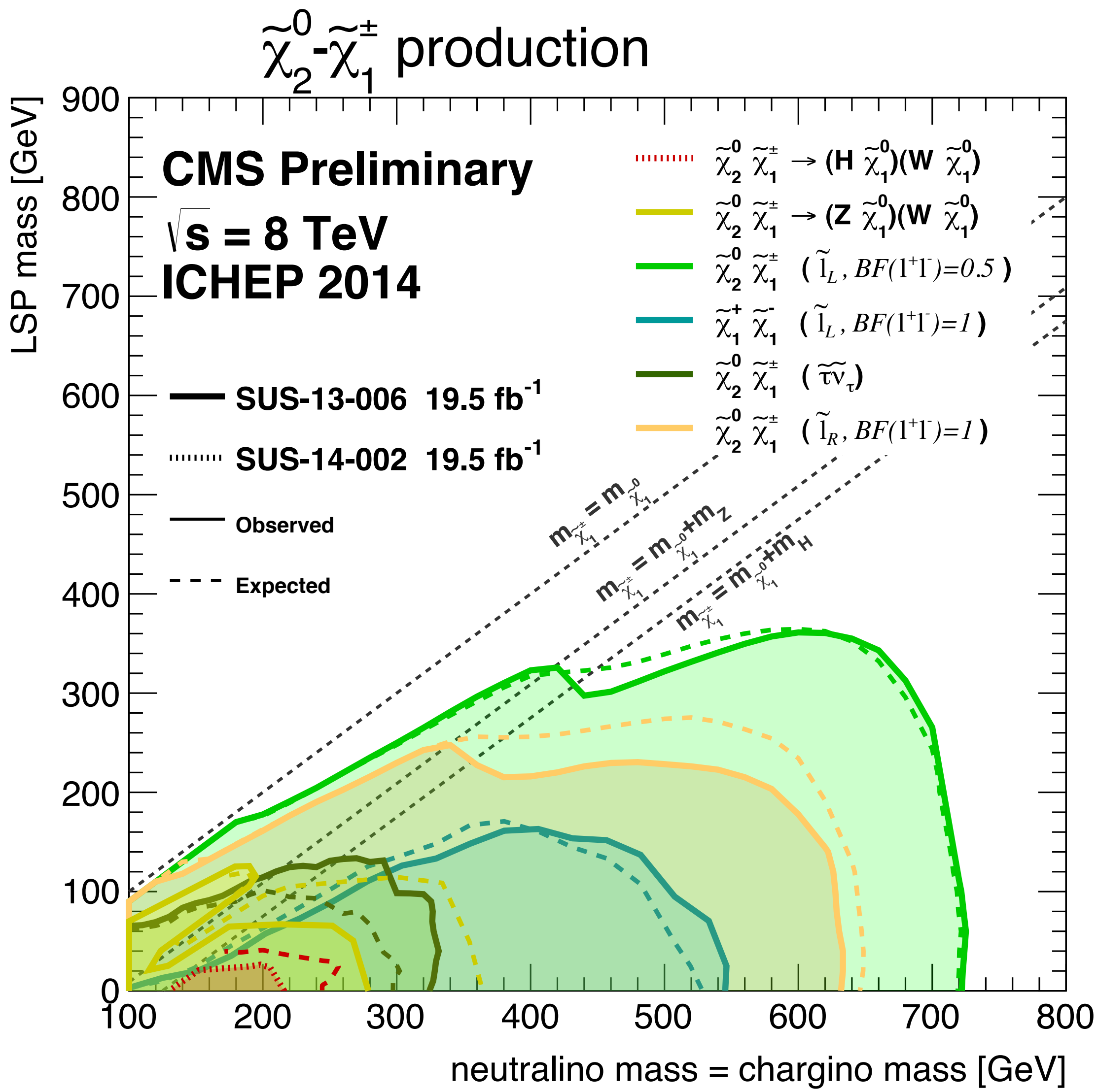
- Set kinematic signal regions to enhance signals w.r.t. SM backgrounds.
  - Discriminating variables: e.g. E_T^{miss}, N_{jets}, effective mass $m_{eff} = E_T^{miss} + H_T$ (scalar sum of jet, lepton p_T)
- Determine background contributions.
  - SM backgrounds: top, multijets, W, Z, VV, Higgs, …
  - Reducible backgrounds: determined from data, depending on analyses.
  - Irreducible backgrounds: normalize MC in data control regions where each background process is dominant.
- Check background predication using validation region data close to signal regions.

- Look for SUSY excess in data signal regions and interpret the observed results.

Search for direct stop production by CMS



Search for EW production by CMS



pMSSM interpretation of CMS results

CMS-SUSY-13-020

Flat pMSSM parameters:
19-dementional priors

$$-3\,\text{TeV} \le M_1, M_2 \le 3\,\text{TeV}$$
$$0 \le M_3 \le 3\,\text{TeV}$$
$$-3\,\text{TeV} \le \mu \le 3\,\text{TeV}$$
$$0 \le m_A \le 3\,\text{TeV}$$
$$2 \le \tan\beta \le 60$$
$$0 \le \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \le 3\,\text{TeV}$$
$$-7\,\text{TeV} \le A_t, A_b, A_\tau \le 7\,\text{TeV},$$

Non-CMS data used

i	Observable $\mu_j(\theta)$	Constraint $D_j^{\text{non-DCS}}$	Likelihood function $L(D_j^{\text{non-DCS}} \mid \mu_j(\theta))$
1a	$BR(b \to s\gamma)$ [43, 44]	$(3.55 \pm 0.23^{stat} \pm 0.24^{th} \pm 0.09^{sys}) \times 10^{-4}$	Gaussian
1b	$BR(b \to s\gamma)$ [45]	$(3.43 \pm 0.21^{stat} \pm 0.24^{th} \pm 0.07^{sys}) \times 10^{-4}$	Gaussian
2a	$BR(B_s \to \mu\mu)$ [46]	observed CLs curve from [46]	$d(1 - CLs)/d(BR(B_s \to \mu\mu))$
2b	$BR(B_s \to \mu\mu)$ [47]	$(2.9 \pm 0.7 \pm 0.29^{th}) \times 10^{-9}$	Gaussian
3a	$R(B_u \to \tau\nu)$[36, 48]	1.63 ± 0.54	Gaussian
3b	$R(B_u \to \tau\nu)$[45]	1.04 ± 0.34	Gaussian
4	Δa_μ [49]	$(26.1 \pm 6.3^{exp} \pm 4.9^{SM} \pm 10.0^{SUSY}) \times 10^{-10}$	Gaussian
5a	m_t [50]	$173.3 \pm 0.5^{stat} \pm 1.3^{sys}$ GeV	Gaussian
5b	m_t [51]	$173.20 \pm 0.87^{stat} \pm 1.3^{sys}$ GeV	Gaussian
6	$m_b(m_b)$ [48]	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian
7	$\alpha_s(M_Z)$ [48]	0.1184 ± 0.0007	Gaussian
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \ge m_h^{low}$ 0 if $m_h < m_h^{low}$
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \le m_h \le m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$
9	sparticle masses	LEP [52] (via micrOMEGAs [37–39])	1 if allowed 0 if excluded

pMSSM points were selected to be compatible with LEP exclusions and flavor physics results.

CMS data used

Analysis	$\sqrt{s}$	L
Hadronic HT + MHT search	7 TeV	4.98 fb^{-1}
Hadronic HT + MET + b-jets search	7 TeV	4.98 fb^{-1}
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{l}$	7 TeV	4.98 fb^{-1}
Hadronic HT + MHT search	8 TeV	19.5 fb^{-1}
Hadronic HT + MET + b-jets search	8 TeV	19.4 fb^{-1}
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{l}$ (ss, 3l, and 4l channels)	8 TeV	19.5 fb^{-1}